X-ray Nanoprobe Investigation Toward the Nano World

The X-ray nanoprobe (XNP) beamline at Taiwan Photon Source (TPS) is designed to utilize fully the brilliant TPS light source for the purpose of resolving the atomic, chemical and electronic structures of – but not limited to – semiconductor-based nano-devices, in tomographic and nondestructive manners with spatial resolution 40 nm, and even less than 10 nm with coherent X-ray techniques.

With innovative X-ray nano-focusing optics, this beamline provides X-ray probes, such as X-ray absorption spectra, X-ray imaging and X-ray diffraction, simultaneously correlative with techniques other than X-ray such as a scanning electron microscope (SEM) and photoluminescence (PL), with temporal resolution 20 ps, with an environment in situ and in operando at a temperature as low as 10 K.

The commissioning of the beamline began in February 2017, directly following the green light of radiation-security inspection. The first monochromatic synchrotron X-ray passed through the entire beamline on March 16. The first XANES Cu K-edge spectrum (**Fig. 1**) was recorded the next day. The monochromatic photon-flux spectrum generated with undulator IU22 was measured, and elegantly fit both the design value and a simulation spectrum based on a measurement of the magnetic fields of the undulator (**Fig. 2**).

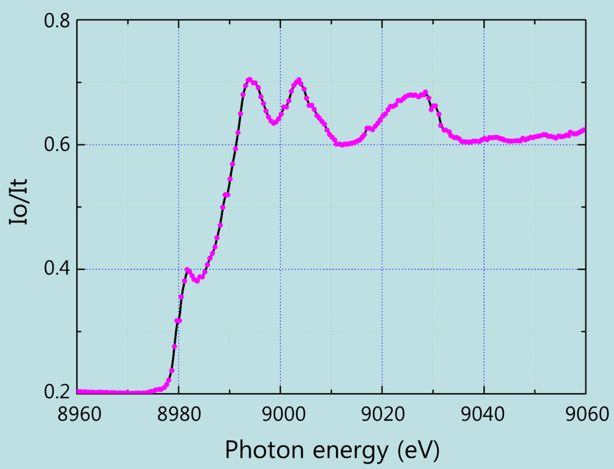


Fig. 1: The first XANES spectrum at the Cu K-edge recorded from beamline **TPS 23A**

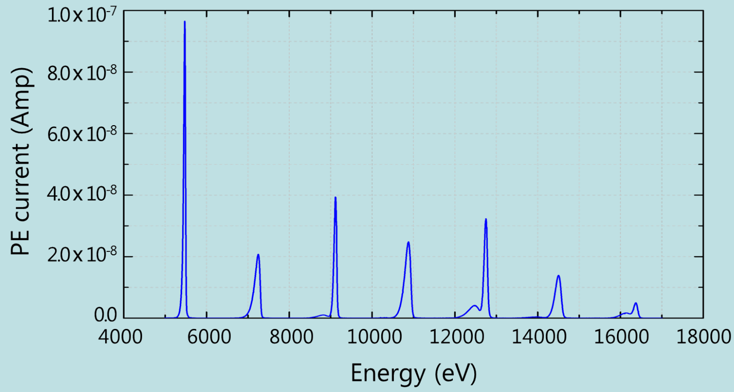


Fig. 2: Measured undulator spectrum at gap 7 mm; the photon flux measured 4.7 x 10^{14} s^{-1} per 0.1% bw at 9.11 keV.

The challenge of the beamline commissioning addressed the performance of a pair of elliptically shaped nested Montel mirrors. In contrast to the sequential Kirkpatrick-Baez (KB) optics, in the Montel optics the two mirrors are nested side by side. The focal spot is formed from two sequential reflections from each mirror. The numerical aperture is thus increased, theoretically by a factor $2^{½}$, resulting in a smaller diffraction-limited focus according to the same factor.

A mirror holder with ten degrees of freedom is designed to align the nested Montel mirrors with great accuracy (1.0–0.01 mrad). The instability of the holder was monitored in real time with three-axis laser interferometers and positional sensitivity 0.5 nm. The focal spot was monitored in situ with a downstream zone plate (outermost zone width 50 nm) to image directly the focal spot at a downstream CCD detector. A 200-nm focal spot was obtained directly after the installation of the Montel mirrors, followed by a 100-nm spot after installing an additional degree of movement of the mirror holder. During the summer shutdown this holder was subject to significant rebuilding to suppress further the ground vibrational resonance coupled to the holder. A symmetric 50-nm focus was eventually realized on applying scanning on the fly to a gold spoke (thickness 100 nm) pattern (**Fig. 3**).

For the sake of commissioning, X-ray fluorescence (XRF) and X-ray excited optical luminescence (XEOL) were measured for ZnO microrods of hexagonal shape (**Figs. 4(a) and 4(b)**). The simultaneous mapping of the Zn K_α fluorescence and the XEOL images

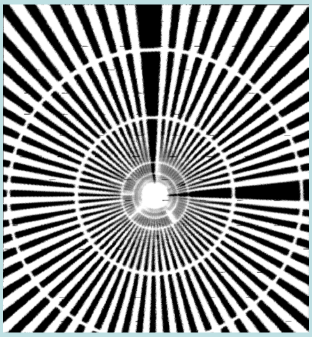


Fig. 3:
A gold spoke pattern with inner line width finer than 50 nm is well resolved.

at the near band edge (NBE) of a ZnO microrod provides a spatial correlation between the light emission and the elemental distribution along the rod. A Fabry-Perot-like interference pattern was found at the defect band from the ZnO XEOL spectrum (**Fig. 4(c)**). For comparison, the cathodoluminescence (CL) imaging of the ZnO wires was performed, using an electron beam from a built-in SEM as the exciting source (**Fig. 4(d)**).

The X-ray nanoprobe (XNP) beamline at TPS has produced the preliminary commissioning results. X-rays of energy 12.8 keV have been focused to 50 nm on adapting innovative nested Montel mirror pairs. The X-ray fluorescence (XRF) and X-ray excited optical luminescence (XEOL) mappings on hexagonal shape ZnO wires were recorded. More challenging tasks are under planning for the year to come. (Reported by Mau-Tsu Tang)

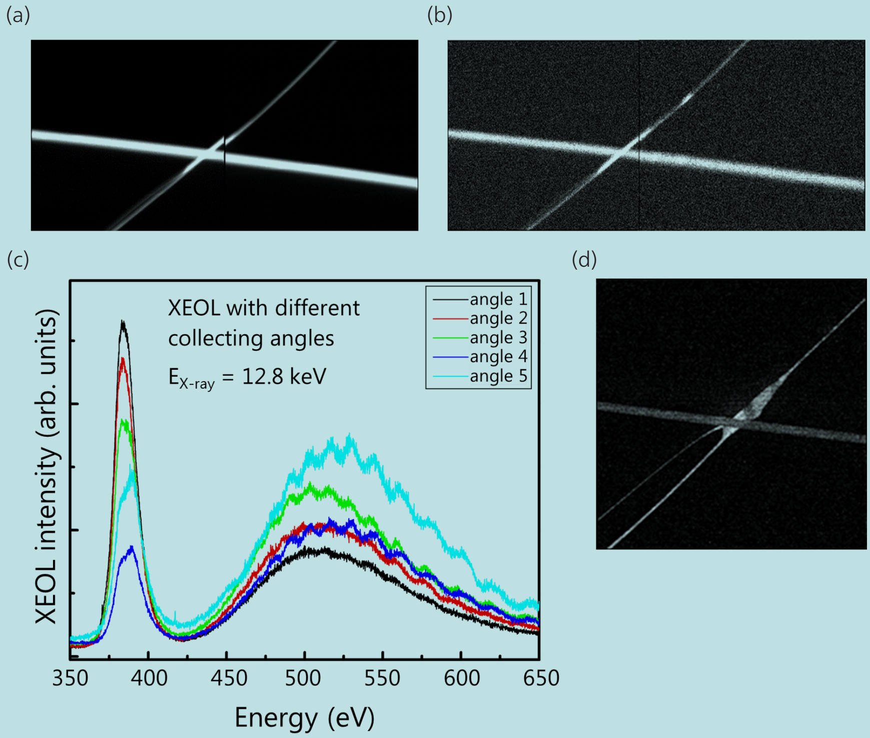
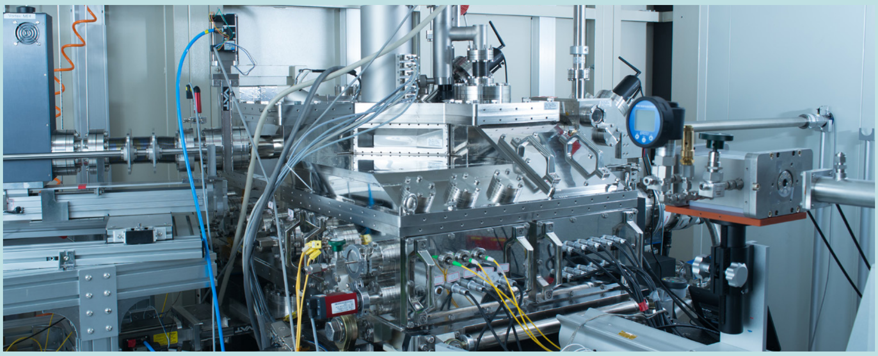
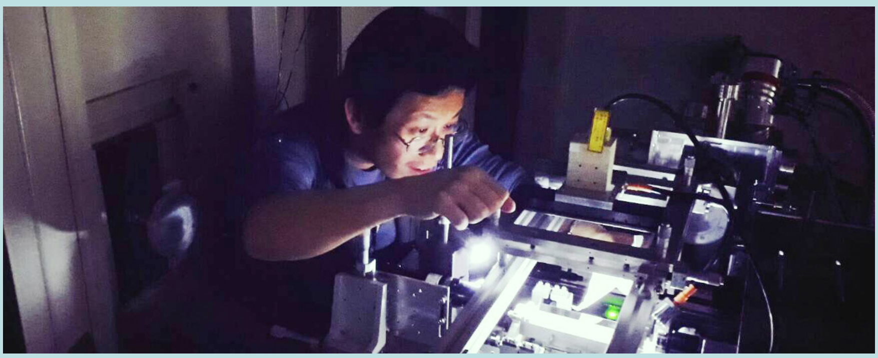


Fig. 4: (a) XRF and (b) XEOL mappings of a ZnO wire were recorded simultaneously at **TPS 23A**. The spatial correlation between the light emission and the elemental distribution along the wire is visibly resolved. (c) At several particular angles of incidence, the XEOL spectra exhibit Fabry-Perot-like interference patterns at the defect band. (d) The electron beam from a built-in SEM served as the exciting source for cathodoluminescence (CL) imaging of the ZnO wire.





TPS 23A is designed to nondestructively probe and resolve the atomic, chemical, and electronic structures of semiconductor based devices, with spatial resolutions of tens of nanometers in tornographic and coherent modes.